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ORIGINAL ARTICLE

Obesity and tooth wear among American adults: the role of sugar-sweetened acidic drinks

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Abstract

Background To explore the association between obesity and tooth wear among American adults and the role of sugar-sweetened acidic drinks consumption in explaining that association.

Methods We analyzed data from 3541 adult participants in the National Health and Nutrition Examination Survey. Obesity was determined using the body mass index and tooth wear was assessed using the modified tooth wear index. Daily intake of four categories of drinks was estimated as the average (drinks/day) of two consecutive 24-h dietary recalls. The association between obesity and number of surfaces with moderate-to-severe tooth wear was assessed in hurdle models adjusting for sociodemographic factors, acid reflux medication, and dental insurance.

Results Overweight and obese adults had more surfaces with moderate-to-severe tooth wear than those with normal body size, after adjusting for confounders. The consumption of sugar-sweetened acidic drinks explained part, but not all the above association. More specifically, the estimate for obesity was fully attenuated, whereas the estimate for overweight was slightly attenuated but remained significant.

Conclusion Obesity was positively associated with tooth wear in American adults. This association was only partially accounted for by the consumption of sugar-sweetened acidic drinks, a common risk factor for both conditions.

Practical implications Dentists must be aware of the health consequences of sugar-sweetened acidic drinks and advocate for reduction in consumption and/or substitution with healthier alternatives.

Keywords Tooth wear · Obesity · Carbonated beverages · Acidic drinks · Adult · Public health dentistry

Introduction

Tooth wear is the loss of dental hard tissues resulting of the interaction between teeth and other materials (abrasion), tooth-to-tooth contact (attrition), or dissolution of hard tissues by acidic substances not caused by bacteria (erosion) [1, 2]. As the prevalence of tooth wear is raising [3, 4], a focus on prevention may prolong the health of the dentition. At the same time, obesity is increasing at an alarming rate globally to the point it is now considered a global pandemic [5, 6].

A few studies have investigated the association between obesity and tooth wear [7–10], with most evidence coming from studies in children [7–9]. However, results are still contradicting as one study in England showed that obese children were more likely to have erosive tooth wear than normal weight children [8], whereas studies in the USA [7] and Brazil [9] reported no association between the two conditions. A study among Swedish young adults found that overweight and obesity were more common among participants with dental erosion than among those with no erosion. However, results were merely descriptive since estimates were not adjusted for potential confounders [10].

There are several potential reasons why obese individuals may be more likely to have tooth wear. First and foremost is the confounding role of factors associated with both obesity and tooth wear. One of those factors is the increased consumption of soft drinks, which is associated with both obesity [11,

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12] and tooth wear [13, 14]. Globally, a rise in soft drinks consumption [15, 16] parallels those in obesity [5, 6] and tooth wear [3, 4]. However, while it is the sugar content of soft drinks (often referred to as sugar-sweetened beverages) what leads to obesity [15], it is the acidic nature of some drinks (such as carbonated drinks and acidic fruit juices) that leads to tooth wear [14]. As such, the key confounder here is the consumption of sugar-sweetened acidic drinks. Beyond the confounding role of sugar-sweetened acidic drinks, it is possible that obesity has an independent effect on tooth wear. Abdominal obesity could be associated with esophageal dysfunction, such as increased acid exposure and reflux symptoms, which in turn may lead to a higher risk of intrinsic erosive tooth wear [17, 18]. More pathological tooth wear and more vomiting and gastroesophageal reflux has also been observed among morbidly obese adults (waiting for bariatric surgery) than healthy controls [19].

The above factors may be interrelated but have yet to be fully investigated. Therefore, the aim of this study was to explore the association between obesity and tooth wear among American adults and the role of the consumption of sugar-sweetened acidic drinks in explaining that association.

Methods

Data source

We used data from the National Health and Nutrition Examination Survey (NHANES) 2003–04, which is part of a series of surveys conducted by the Center for Disease Control and Prevention (CDC) to assess the health and nutritional status of the non-institutionalized civilian population aged 2 years and older residing in the USA [20]. The 2003–04 NHANES is the only survey that included an expanded oral health section providing information on oral health conditions that were never assessed previously and have not been assessed again since then.

The selection of survey participants was conducted by stratified, multistage probability sampling to recruit a representative sample. Oversampling was conducted on certain subgroups which included non-Hispanic blacks, Mexican Americans, and participants aged 12 to 19 years and 60 years or more. Data were collected through phone interviews, face-to-face interviews, and clinical examinations. A total of 10,122 individuals of the eligible population agreed to take part in the survey (79% response rate). The expanded oral health examination was conducted on participants aged 13 years and older and included 8272 participants (76%) [20]. The NHANES 2003–04 survey included 4308 participants aged 18 years and over with complete tooth wear. We excluded 767 participants because of missing data on obesity, dietary data, and confounders. Therefore, the study sample included 3541 participants.

Variables selection

The outcome variable for this study was tooth wear, which was assessed using the modified tooth wear index (TWI), has been used in the UK Adult Dental Health Survey [21]. The clinical assessment included visual examination of the facial, lingual, and incisal surfaces of the 12 anterior teeth as well as occlusal surfaces of the first molars (40 tooth surfaces overall). Tooth surfaces were scored as sound (any wear restricted to the enamel); mild tooth wear (loss of enamel just exposing dentine); moderate tooth wear (dentine exposure greater than one-third of the surface); or severe tooth wear (complete loss of enamel, pulp exposure, or exposure of secondary dentine). Oral clinical examinations were conducted by two trained and calibrated examiners. Inter-examiner reliability for the tooth wear examination gave a percent agreement of 87.7% and a kappa of 0.80 [20]. The number of surfaces with moderate-to-severe tooth wear was the outcome for this study.

The exposure was obesity measured using the body mass index (BMI). Trained health technicians measured participants' weight and height using standard protocols and equipment [22]. BMI was calculated as body weight (in kilograms) divided by the square of height (in meters) and used to classify participants as normal ($BMI < 25$), overweight ($25 \leq BMI \leq 29.9$), or obese ($BMI \geq 30$).

Several confounders were also selected for analysis based on previous studies [23, 24]. A basic set of confounders included demographic characteristics (sex, age, race/ethnicity), socioeconomic position (education and poverty income ratio), acid reflux medication (antacids and anti-reflux medication, as a proxy for gastroesophageal reflux symptoms), and dental insurance coverage. The key confounder in our analysis was the intake of sugar-sweetened acidic drinks, which was estimated from two non-consecutive 24-h recalls [25]. The first 24-h dietary recall was performed in person by trained interviewers in the mobile examination center, while the second 24-h dietary recall was conducted by telephone 3 to 10 days after the examination. Dietary recall data were used to measure an average intake (drinks/day) across the 2 days of four different categories of drinks: sugar-sweetened acidic drinks (SSA: sweetened soda, non-100% fruit juice, sweetened sports drinks), sugar-sweetened non-acidic drinks (SSNA: sugar-sweetened coffee, tea- and milk-based products with sugar), non-sugar-sweetened acidic drinks (NSSA: diet soft drinks, 100% fruit juice or flavored sparkling water), non-sugar-sweetened non-acidic drinks (NSSNA: non-sugar-sweetened coffee, tea- and milk-based products). The specific USDA food codes included in each of the four categories of drinks are listed in the Appendix.

Data analysis

Data were analyzed using Stata/SE version 14.1 (Stata Corp., College Station TX, USA). All analyses were weighted to produce a representative sample and to take account of the variation in cluster size and different sampling rates for clusters within strata.

The distribution of the number of surfaces with moderate-to-severe tooth wear was positively skewed, with many participants having zero counts. Therefore, a hurdle model was preferred to model associations with the number of surfaces with moderate-to-severe tooth wear. Hurdle models account for the excessive proportion of zero values and over-dispersion [26, 27]. They include two components. The first component estimates the probability of being a non-zero (positive) count from a binary logit model. Odds ratios (OR) were reported for this component of the model, which represent the probability of having moderate-to-severe tooth wear. The second component estimates the mean number of surfaces with moderate-to-severe tooth wear among those with positive counts only (those with tooth wear) using a truncated negative binomial model. Rate ratios (RRs) were reported for this component, which represent how higher/lower the mean number of surfaces with moderate-to-severe tooth wear was in one group compared to the reference group, among those with the condition [26, 27].

We first examined the association between each type of drink (SSA, SSNA, NSSA, NSSNA) and the number of surfaces with moderate-to-severe tooth wear through a series of regression models: Model 1A was unadjusted; model 1B was adjusted for confounders (sex, age groups, race/ethnicity, education, poverty income ratio, dental insurance, and acid reflux medication); and model 2C was additionally adjusted for the remaining types of drinks. We then examined the association between BMI and the number of surfaces with moderate-to-severe tooth wear through a series of regression models: model 2A was unadjusted; model 2B was adjusted for confounders (sex, age groups, race/ethnicity, education, poverty income ratio, dental insurance, and acid reflux medication); models 2C to 2F were additionally adjusted for one type of drink at a time (model 2C: SSA, model 2D: SSNA, model 2E: NSSA, model 2F: NSSNA); and model 3F was adjusted for confounders and all four types of drinks simultaneously.

Results

There were some differences between the study sample and those not included due to missing values on covariates (Table 1). On average, participants in the study sample were older (43.9 versus 39.9 years, $p = 0.001$) and reported greater consumption of NSSNA drinks (1.51 versus 1.24 drinks/day, $p = 0.038$) than those excluded. In the study sample, the prevalence of moderate-to-severe tooth wear was 12.1%, with an average of 3.4 (95% confidence interval 2.9–3.9) surfaces affected among those with the condition. Also, 33.7% and 32% of adults were overweight and obese, respectively.

The association of the daily intake of different types of drinks with moderate-to-severe tooth wear is presented in Table 2. The intakes of SSA, SSNA, NSSA, and NSSNA drinks were not associated with the probability of having moderate-to-severe tooth wear. However, the intakes of SSA and NSSNA drinks were significantly associated with the number of surfaces with moderate-to-severe tooth wear among those with the condition (model 1B). In those with tooth wear, the number of surfaces affected was 1.40 (95% CI 1.14–1.73) times higher per additional SSA drink consumed per day. On the other hand, the number of surfaces with moderate-to-severe tooth wear was 17% (RR 0.83, 95% CI 0.75–0.93) lower per additional NSSNA drinks consumed per day. These two associations were slightly attenuated but remained significant after further adjustment for other types of drinks (RR of 1.34 and 0.86 for SSA and NSSNA drinks from model 1C, respectively).

BMI was not associated with tooth wear in the unadjusted model (model 2A in Table 3). After adjustment for confounders (model 2B), BMI was not significantly associated with the probability of having moderate-to-severe tooth wear, but it was associated with the number of surfaces with moderate-to-severe tooth wear among those with the condition. In those with tooth wear, the number of surfaces affected was, respectively, 1.72 (95% CI 1.09–2.71) and 1.61 (95% CI 1.00–2.58) times higher in overweight and obese adults than in those with normal body size. However, the estimate for obese adults was fully attenuated after further adjustment for either SSA, NSSA, or NSSNA drinks (models 2C, 2E, and 2F, respectively). The estimate for obese adults remained significant after adjustment for SSNA drinks (RR 1.62, 95% CI 1.01–2.58 from model 2D). When adjusted for confounders and all four types of drinks (model 2G), the estimate for overweight remained significant (RR 1.56, 95% CI 1.04–2.34), while the estimate for obese adults was fully attenuated (RR 1.41, 95% CI 0.90–2.21).

Discussion

This study first found that obesity was positively associated with tooth wear, independently of known risk factors for tooth wear. Interestingly, this association was found with the number of surfaces with moderate-to-severe tooth wear among those with the condition (i.e., an indication of its severity), but not with the prevalence of tooth wear. Our finding reinforces the opinion that a binary classification of individuals as simply having or not having tooth wear (prevalence) hides

Table 1 Characteristics of the study sample ($n = 3541$) and comparison with those excluded due to missing data on covariates

Explanatory variables	Excluded		Study sample		p value
Sex, n^a %					0.514
Men	162	50.5	1678	48.0	
Women	177	49.5	1863	52.0	
Age groups, n^a %					0.001
18–24 years	109	29.7	715	14.1	
25–34 years	44	15.0	621	20.1	
35–44 years	40	17.1	561	19.7	
45–54 years	37	17.3	515	20.3	
55–64 years	40	10.0	411	12.8	
65–74 years	35	6.1	392	7.8	
75+ years	34	4.9	326	5.2	
Race/ethnicity, n^a %					0.538
White, Non-Hispanic	166	72.8	1807	72.7	
Black, Non-Hispanic	82	12.4	722	11.4	
Hispanic	76	9.0	882	11.4	
Others	15	5.8	130	4.5	
Education, n^a %					0.200
Less than high school	102	15.4	929	15.6	
High school	100	32.8	885	25.2	
More than high school	134	51.9	1727	59.2	
Poverty income ratio, n^a %					0.059
< 100%	49	27.8	692	12.5	
101–200%	48	23.8	887	19.5	
201–300%	21	14.5	549	15.6	
301–400%	16	15.4	455	15.1	
≥ 401%	19	18.6	958	37.4	
Dental insurance, n^a %					0.260
Not covered	104	53.3	1762	45.9	
Covered	95	46.7	1779	54.1	
Acid reflux medication, n^a %					0.650
None	258	77.4	2724	74.2	
Over the counter only	41	14.2	505	16.3	
Prescribed	35	8.4	312	9.4	
BMI groups, n^a %					0.542
Normal	108	39.3	1189	34.5	
Overweight	93	32.8	1189	33.7	
Obese	93	27.9	1163	31.9	
SSA drinks, mean (SD)	0.89	(0.94)	0.89	(0.97)	0.983
SSNA drinks, mean (SD)	0.17	(0.50)	0.14	(0.37)	0.587
NSSA drinks, mean (SD)	0.29	(0.56)	0.38	(0.69)	0.089
NSSNA drinks, mean (SD)	1.24	(1.21)	1.51	(1.29)	0.038
Surfaces with tooth wear, mean (SD)	0.38	(1.76)	0.41	(1.63)	0.700

[a] Counts are unweighted

SSA, sugar-sweetened acidic drinks; SSNA, sugar-sweetened non-acidic drinks, NSSA, non-sugar-sweetened acidic drinks; NSSNA, non-sugar-sweetened non-acidic drinks; SD, standard deviation

fine-grained information on the extent of the condition, and it may potentially mask associations [24].

Beyond this initial finding, we also set up to explore the role of the consumption of SSA drinks in explaining the above association because this category of beverages is associated with both obesity and tooth wear. Therefore, the consumption of SSA drinks may be a common risk factor for both conditions. As expected, SSA drinks consumption was positively

Table 2 Association between different types of drinks and number of surfaces with moderate-to-severe tooth wear in American adults (n = 3541)

Model[a]	Type of drinks[b]	Logit portion[c] OR [95% CI]	NB portion[c] RR [95% CI]
Model 1A	SSA drinks	0.68 [0.58–0.80]	1.17 [0.97–1.41]
	SSNA drinks	0.96 [0.57–1.61]	1.00 [0.71–1.42]
	NSSA drinks	1.06 [0.87–1.30]	0.94 [0.79–1.14]
	NSSNA drinks	1.19 [1.08–1.31]*	0.95 [0.88–1.03]
Model 1B	SSA drinks	0.82 [0.67–1.01]	1.40 [1.14–1.73]*
	SSNA drinks	0.97 [0.59–1.60]	1.08 [0.75–1.57]
	NSSA drinks	1.06 [0.85–1.34]	1.01 [0.79–1.29]
	NSSNA drinks	0.92 [0.77–1.10]	0.83 [0.75–0.93]*
Model 1C	SSA drinks	0.79 [0.61–1.03]	1.34 [1.08–1.66]*
	SSNA drinks	0.93 [0.56–1.53]	0.96 [0.68–1.36]
	NSSA drinks	0.98 [0.72–1.32]	1.02 [0.87–1.20]
	NSSNA drinks	0.89 [0.74–1.07]	0.86 [0.77–0.96]*

[a] Model 1A was unadjusted; model 1B was adjusted for sex, age groups, race/ethnicity, education, poverty income ratio, dental insurance, and acid reflux medication; model 1C was additionally adjusted for the other three categories of drinks

[b] SSA, sugar-sweetened acidic drinks; SSNA, sugar-sweetened non-acidic drinks; NSSA, non-sugar-sweetened acidic drinks; NSSNA, non-sugar-sweetened non-acidic drinks

[c] Hurdle regression model was used. Odds ratio (OR) were reported for the logit portion and rate ratios (RR) for the negative binomial (NB) portion. ORs represent the probability of having moderate-to-severe tooth wear in one group compared to the reference group. RRs represent how higher/lower the mean number of surfaces with moderate-to-severe tooth wear is in one group compared to the reference group, among those with the condition

*$p < 0.05$

Table 3 Models for the association between body mass index (BMI) and number of surfaces with moderate-to-severe tooth wear among American adults (n = 3541)

Model[a]	BMI groups	Logit portion[b] OR [95% CI]	NB portion[b] RR [95% CI]
Model 2A	Normal	1.00 [reference]	1.00 [reference]
	Overweight	1.09 [0.65–1.84]	1.53 [0.96–2.45]
	Obese	1.12 [0.69–1.81]	1.55 [0.94–2.57]
Model 2B	Normal	1.00 [reference]	1.00 [reference]
	Overweight	0.65 [0.37–1.15]	1.72 [1.09–2.71]*
	Obese	0.83 [0.51–1.34]	1.61 [1.00–2.58]*
Model 2C	Normal	1.00 [reference]	1.00 [reference]
	Overweight	0.65 [0.38–1.13]	1.62 [1.09–2.42]*
	Obese	0.83 [0.52–1.31]	1.54 [0.98–2.44]
Model 2D	Normal	1.00 [reference]	1.00 [reference]
	Overweight	0.65 [0.37–1.15]	1.72 [1.09–2.70]*
	Obese	0.83 [0.51–1.34]	1.62 [1.01–2.58]*
Model 2E	Normal	1.00 [reference]	1.00 [reference]
	Overweight	0.65 [0.37–1.15]	1.71 [1.08–2.71]*
	Obese	0.82 [0.50–1.34]	1.59 [0.99–2.56]
Model 2F	Normal	1.00 [reference]	1.00 [reference]
	Overweight	0.65 [0.36–1.16]	1.63 [1.03–2.59]*
	Obese	0.81 [0.49–1.34]	1.46 [0.89–2.37]
Model 2G	Normal	1.00 [reference]	1.00 [reference]
	Overweight	0.65 [0.37–1.15]	1.56 [1.04–2.34]*
	Obese	0.81 [0.49–1.34]	1.41 [0.90–2.21]

[a] Model 2A was unadjusted; model 2B was adjusted for confounders (sex, age groups, race/ethnicity, education, poverty income ratio, dental insurance, and acid reflux medication); model 2C was adjusted for confounders and sugar-sweetened acidic (SSA) drinks; model 2D was adjusted for confounders and sugar-sweetened non-acidic (SSNA) drinks; model 2E was adjusted for confounders and non-sugar-sweetened acidic (NSSA) drinks; model 2F was adjusted for confounders and non-sugar-sweetened non-acidic (NSSNA) drinks; model 2G was adjusted for confounders and all four types of drinks

[b] Hurdle regression model was used. Odds ratio (OR) were reported for the logit portion and rate ratios (RR) for the negative binomial (NB) portion. ORs represent the probability of having moderate-to-severe tooth wear in one group compared to the reference group. RRs represent how higher/lower the mean number of surfaces with moderate-to-severe tooth wear is in one group compared to the reference group, among those with the condition

*$p < 0.05$

associated with tooth wear and explained part of the association between obesity and tooth wear. Indeed, the estimate for obesity, but not that for overweight, becomes fully attenuated when SSA drinks consumption was included in the regression model. Accounting for other categories of drinks did not alter that finding. It is possible that obese adults have already been diagnosed with the condition and cut down on their usual intake of sugar-sweetened beverages (some of which are acidic). Contrarily, overweight adults might still be indulging in their (high) consumption of SSA drinks. The fact that the association between overweight and tooth wear was not explained away by the intake of SSA drinks implies that other factors may be at play. There is considerable evidence linking obesity with gastroesophageal reflux disease (GERD) symptoms [17, 18], a cause of erosive tooth wear [28, 29]. Increased abdominal pressure caused by central adiposity relaxes the lower esophageal sphincter, thus exposing the esophageal and oral mucosa to gastric content [17]. On the other hand, adipose tissue is metabolically active and induces the production of inflammatory cytokines which may play a role in GERD [18].

An additional finding of this study was that the consumption of NSSNA drinks was inversely associated with tooth wear (among those with the condition only), suggesting a potential protective effect. In this study, NSSNA drinks included items like unsweetened tea, coffee, milk, and non-sugar-sweetened milk-based products. Previously, it has been reported that milk-based products were associated with reduced tooth wear [14], although another review reported no association [13]. This protective effect could be due to substitution of the acidic beverage with a less acidic counterpart [14]

or, less likely, due to the calcium and phosphate levels in the drinks encouraging remineralization or providing sacrificial minerals in the event of an acid challenge [30–32].

The present findings have implications on practice and future research. These results suggest that SSA drinks consumption is a common root for obesity and tooth wear. Addressing their consumption provides an important target area for healthcare practitioners to reduce the health impact of both conditions. It is probably easier to advocate their substitution with NSSNA drinks rather than reducing their consumption all together and recent behavioral research has shown relative success with this method [33]. Further research in this area is needed, and it would be useful to include tooth wear assessment in national health surveys to continue this work. There is also a need for longitudinal studies using multiple dietary assessments, repeated body measurements, and more accurate quantification of tooth wear progression to confirm this relationship.

Some limitations of this study need to be addressed. First, this study was based on cross-sectional data and as such unable to test for causal associations. Second, our study sample represented 82% of eligible adults, which may raise concerns about representativeness. Since older participants and high-NSSNA drinkers were more likely to be included in the study sample, the present findings should be generalized with caution. Third, tooth wear assessment was based on partial-mouth examination which may not be as valid as full-mouth examination [34]. However, past studies have indicated that anterior teeth and the occlusal surface of first molars are the most commonly affected by tooth wear [35, 36]. Fourth, we assessed participants' dietary intake through 24-h recalls, which do not measure long-term dietary habits of individuals and are prone to recall bias and under/over-reporting. Compared with food frequency questionnaire data also available in NHANES, the use of multiple 24-h recalls provided information regarding a significantly larger number of drinks that were combined into four categories. Finally, we were unable to control for GERD (although we used a proxy based on acid reflux medication) or vomiting eating disorders which are known risk factors for tooth wear.

In conclusion, obesity was positively associated with tooth wear in this national sample of American adults. This association was partially accounted for by the consumption of sugar-sweetened acidic drinks, a common risk factor for both conditions. All the findings were observed with the extent (among those with the condition) but not the prevalence of moderate-to-severe tooth wear.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Written informed consent was obtained from every participant in the study.

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